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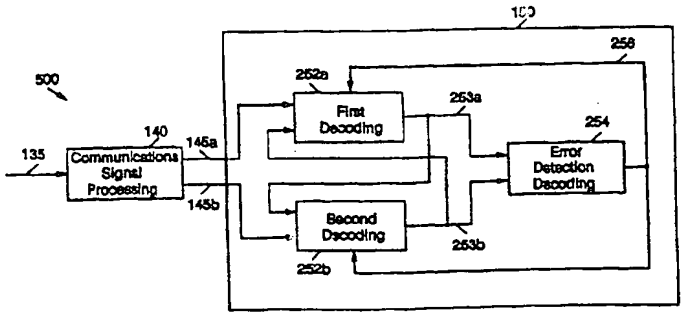
(54) Title: COMMUNICATIONS SYSTEMS AND METHODS EMPLOYING SELECTIVE RECURSIVE DECODING

(57) Abstract

A source sequence of symbols is communicated over a communications medium by encoding the source sequence according to respective first and second error correction codes to produce respective first and second encoded sequences of symbols. The first and second encoded sequences are processed to produce a communications signal, which is then communicated over the communications medium. The communicated communications signal is processed to produce first and second received sequences of symbols corresponding to the first and second encoded sequences, respectively. The first and second received sequences are selectively recursively decoded according to the associated error correction codes augmented by previous estimates of a symbol of the source sequence to repeatedly produce revised estimates of a symbol until an estimate satisfying a predetermined reliability criteria is obtained. The first and second received sequences may be selectively recursively decoded by maximum likelihood decoding the first received sequence to produce a first estimate of a symbol of the source sequence and a path metric associated therewith, and decoding the second received sequence to produce a second estimate of the first symbol if a predetermined function of the path metric associated with the first estimate is outside of a predetermined range. Similarly, the received sequences may be selectively decoded by maximum a posteriori (MAP) decoding the first received sequence to produce a first MAP estimate of a symbol of the source sequence and a reliability metric associated therewith, and decoding the second received sequence to produce a second estimate of the first symbol if the reliability metric associated with the first MAP estimate is outside of a predetermined range. Encoding of the source sequnce according to the first and second error correction codes may be preceded by encoding the source sequence according to an error detection code, e.g., a CRC, and selective recursive decoding may include decoding the first received sequence according to the first error correction code to produce an estimate of a symbol of the source sequence, and then decoding the estimate according to the error detection code to produce the reliability metric for the estimate.



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COMMUNICATIONS SYSTEMS AND METHODS EMPLOYING SELECTIVE RECURSIVE DECODING

Field of the Invention

The present invention relates to communications systems and methods, in particular, to communications systems and methods employing error correction.

Background of the Invention

In a typical communications system, information is transmitted from a sender in the form of a communications signal representing the information. The communications signal typically is communicated to a receiving unit over a communications medium such as a radio, optical fiber, coaxial cable or similar link, which may introduce disturbances such as noise, delay, and distortion in the communications signal. These disturbance can induce errors when recovering the original information from the communicated communications signal at the receiving unit.

Conventional responses to overcome this problem include increasing the power level of the transmitted communications signal in order to increase the probability that the original information may be recovered. However, the ability to increase transmitter power may be limited due to power limitations of transmitter electronics, regulations on peak signal power levels and constraints on the power available for transmitting, for example, power supply limitations in devices such as mobile radiotelephones and satellites.

Redundancy may be introduced into a communications signal by using error control coding techniques. Redundant symbols supplied in a code such as block or convolutional code can provide an additional "separation" between the words of the

set of code words, thus allowing a receiver which receives a group of symbols over a noisy communications channel to more easily discriminate between words of the set of code words, typically by determining which member of the set of code words most closely resembles the received group of symbols.

Many error control codes are effective at correcting random errors, e.g., errors which affect individual symbols in a random distributed fashion, while others are effective at compensating for so-called "burst" errors, e.g., errors which persist over several consecutive symbols. To compensate for burst errors, many systems employ interleaving which reorders symbols in a stream such that burst errors are more randomly distributed, for example, by using a device which stores the symbol stream in a matrix by rows and then retrieves the stored symbols by columns, such that the sequence retrieved from the device represents a reordering of the original input sequence. To combat random and burst errors, a system may employ a combination of random error correction encoding and interleaving, for example a cascade of a binary convolutional code and an interleaver, or a so-called "turbo coding " scheme, as described in United States Patent 5, 446, 747 to Berrou et al. Turbo coding schemes typically employ a first code to encode a source data stream and a second code to encode an interleaved version of the source data stream to produce first and second encoded streams which are multiplexed and communicated over a channel. The received data stream typically is demultiplexed and decoded by first and second decoders employing the first and second codes, with appropriate interleaving and deinterleaving, with the output of one decoder being used to aid the other decoder in decoding the demultiplexed sequences in an iterative fashion.

While techniques such as turbo-coding are generally effective at reducing error rates for information communicated over a channel, conventional decoding schemes may not optimally decode the received information under various channel conditions. Turbo-coding can provide improved power efficiency, but may involve a large number of computations which may be unnecessary under favorable channel conditions and which may unnecessarily consume power.

Summary of the Invention

In light of the foregoing, it is an object of the present invention to provide communications systems and methods which more efficiently decode communications signals representing parallel encoded source sequences.

This and other objects features and advantages are provided according to the present invention by communications systems and methods in which a communications signal representing a parallel encoded source sequence is selectively recursively decoded to produce estimates of a symbol in the source sequence based on a respective reliability associated with a respective revised estimate of the symbol. Preferably, the communications signal is processed to produce first and second sequences corresponding to the first and second error correction codes used to produce the communications signal, and then the received sequences are decoded in respective first and second soft output decoders. In a respective soft output decoder, a sequence is decoded according to the corresponding error correction code, augmented by previous estimates produced by the other decoder. Preferably, one of the first and second soft output decoders is chosen to first estimate the symbol based on a signal characteristic, e.g., signal strength, associated with the first and second received sequences. A selected group of symbols or bits of the source sequence, for example, a group of less significant symbols or bits, may be nonrecursive decoded, while another group of symbols or bits, for example, a group of more significant symbols or bits, may be selectively recursively decoded. Efficient techniques for decoding parallel encoded signals are thereby provided.

In particular, according to the present invention, a communications system includes encoding means for encoding a source sequence according to respective first and second error correction codes to produce respective first and second encoded sequences of symbols. Communications symbol processing means are responsive to the encoding means for processing the first and second encoded sequences to produce a communications signal. Communications signal communicating means are responsive to the communications symbol processing means for communicating the communications signal over a communications medium, and communications signal processing means are responsive to the communications signal communicating means for processing the communicated communications signal to produce first and second

received sequences of symbols corresponding to the first and second encoded sequences, respectively. Selective recursive decoding means are responsive to the communications signal processing means for selectively recursively decoding the first and second received sequences according to the respective first and second codes augmented by previous estimates of a symbol of the source sequence to repeatedly produce revised estimates of the symbol until a revised estimate satisfying a predetermined reliability criterion is obtained.

The encoding means may include first encoding means for encoding the source sequence according to the first error correction code to produce the first encoded sequence, and second encoding means for encoding the source sequence according to the second error correction code to produce the second encoded sequence. The communications symbols processing means may include multiplexing means, responsive to the first and second encoding means, for multiplexing the first and second encoded sequences to produce a multiplexed sequence of symbols. Means may be provided, responsive to the multiplexing means, for processing the multiplexed sequence to produce the communications signal. According to one aspect, the encoding means further includes interleaving means for interleaving the source sequence to produce an interleaved source sequence, and one of the first and second encoding means is responsive to the encoding means for encoding the interleaved source sequence.

According to one embodiment, the selective recursive decoding means includes first soft output decoding means, responsive to the communications signal processing means, for decoding the first received sequence according to the first error correction code, and second soft output decoding means, responsive to the communications signal processing means, for decoding the second received sequence according to the second error correction code. The first soft output decoding means is responsive to the second soft output decoding means to decode the first received sequence according to the first error correction code augmented by a soft output produced by the second soft output decoding means to produce a first estimate of a symbol of the source sequence if a previous estimate of the symbol produced by the second soft output decoding means fails to satisfy a predetermined reliability

criterion. The second soft output decoding means is responsive to the first soft output decoding means to decode the second received sequence according to the second error correction code augmented by a soft output produced by the first soft output decoding means to produce a second estimate of a symbol of the source sequence if a previous estimate of the symbol produced by the second soft output decoding means fails to satisfy a predetermined reliability criterion.

According to another embodiment, the system includes error detection encoding means for encoding the source sequence according to an error detection code to produce an error detection encoded sequence, while the encoding means includes means for encoding the error detection encoded sequence according to the first and second error correction codes to produce the first and second encoded sequences. The selective recursive decoding means includes first decoding means, responsive to the communications signal processing means, for decoding the first received sequence according to the first error correction code to produce an estimate of a symbol of the source sequence, second decoding means, responsive to the communications signal processing means, for decoding the second received sequence according to the second error correction code to produce an estimate of a symbol of the source sequence, and error detection decoding means, responsive to the first and second decoding means, for decoding an estimate produced by the first decoding means or by the second decoding means to thereby produce a reliability metric for the estimate. The first decoding means is responsive to the error detection decoding means to decode the first received sequence according to the first error correction code augmented by a reliability metric produced by the error detection decoding means to produce a first estimate of a symbol of the source sequence if the reliability metric produced by the error detection decoding means indicates that a previous estimate of the symbol produced by the second decoding means fails to satisfy a predetermined reliability criterion. The second decoding means is responsive to the error detection decoding means to decode the second received sequence according to the second error correction code augmented by a reliability metric produced by the error detection decoding means to produce a second estimate of a symbol of the source sequence if the reliability metric produced by the error detection decoding

means indicates that a previous estimate of the symbol produced by the first decoding means fails to satisfy a predetermined reliability criterion.

According to another aspect of the invention, the selective recursive decoding means may include means for maximum likelihood decoding the first received sequence to produce a first estimate of a symbol of the source sequence and a path metric associated therewith. Means are provided, responsive to the means for maximum likelihood decoding, for decoding the second received sequence to produce a second estimate of the symbol if a predetermined function of the path metric associated with the first estimate is outside of a predetermined range. According to another aspect, the selective recursive decoding means includes means for maximum a posteriori (MAP) decoding the first received sequence to produce a first MAP estimate of a symbol of the source sequence and a reliability metric associated therewith, and means are provided, responsive to the means for MAP decoding, for decoding the second received sequence to produce a second estimate of the symbol if the reliability metric associated with the first MAP estimate is outside of a predetermined range.

The system may further includes means for nonrecursively decoding at least one of the first and second received sequences according to the associated error correction codes to produce estimates of a first group of symbols in the source sequence. The selective recursive decoding means may include means for recursively decoding the first and second received sequences to produce estimates of a second group of symbols of the source sequence. The second group of symbols may represent information of a greater importance than information represented by the first group of symbols, for example, the second group of symbols may include symbols of greater significance than symbols included in the first group of symbols. By nonrecursively decoding less important symbols, decoding may be achieved with fewer computations.

The system may also include error detection encoding means for encoding the source sequence according to an error detection code, e.g., a cyclic redundancy code (CRC), to produce an error detection encoded sequence, and the encoding means may include means for encoding the error detection encoded sequence according to the

first and second error correction codes to produce the first and second encoded sequences. The selective recursive decoding means may include means for decoding the first received sequence according to the first error correction code to produce an estimate of a symbol of the source sequence, and means for decoding the estimate according to the error detection code to produce a reliability metric for the estimate.

According to another aspect, the selective recursive decoding means includes means for first decoding one of the received sequences having a preferred signal characteristic, e.g., a greater signal strength, associated therewith. Means for determining a respective signal characteristic for a respective one of the received sequences may also be provided. The selective recursive decoding means may also include means for decoding the first received sequence to produce a first estimate of a symbol of the source sequence, the first estimate having a reliability associated therewith, and means for decoding the second received sequence according to the second error correction code augmented by the first estimate of the symbol of the source sequence to produce a second estimate of the symbol if the first estimate of the symbol satisfies a first reliability criterion, and for decoding the second received sequence according to the second error correction code augmented by a predetermined reference value if the first estimate of the symbol satisfies a second reliability criterion. The first predetermined reliability criterion may represent a greater reliability than the second predetermined reliability criterion.

According to method aspects, a source sequence of symbols is communicated over a communications medium by encoding the source sequence according to respective first and second error correction codes to produce respective first and second encoded sequences of symbols. The first and second encoded sequences are processed to produce a communications signal, which is then communicated over the communications medium. The communicated communications signal is processed to produce first and second received sequences of symbols corresponding to the first and second encoded sequences, respectively. The first and second received sequences are selectively recursively decoded according to the associated error correction codes augmented by previous estimates of a symbol of the source sequence to repeatedly produce revised estimates of the symbol until an estimate satisfying a predetermined

reliability criteria is obtained.

The first and second received sequences may be selectively recursively decoded by maximum likelihood decoding the first received sequence to produce a first estimate of a symbol of the source sequence and a path metric associated therewith, and decoding the second received sequence to produce a second estimate of the first symbol if a predetermined function of the path metric associated with the first estimate is outside of a predetermined range. Similarly, the received sequences may be selectively decoded by maximum a posteriori (MAP) decoding the first received sequence to produce a first MAP estimate of a symbol of the source sequence and a reliability metric associated therewith, and decoding the second received sequence to produce a second estimate of the first symbol if the reliability metric associated with the first MAP estimate is outside of a predetermined range. According to another method aspect, encoding of the source sequence according to the first and second error correction codes may be preceded by encoding the source sequence according to an error detection code, e.g., a CRC, and selective recursive decoding may include decoding the first received sequence according to the first error correction code to produce an estimate of a symbol of the source sequence, and then decoding the estimate according to the error detection code to produce the reliability metric for the estimate. The first received sequence may be decoded to produce a first estimate of a symbol of the source sequence and the second received sequence may then be decoded according to the second error correction code augmented by the first estimate of the symbol if the first estimate satisfies a first reliability criterion or according to the second error correction code augmented by a predetermined reference value if the first estimate satisfies a second reliability criterion. The first predetermined reliability criterion preferably represents a greater reliability than the second predetermined reliability criterion.

Brief Description of the Drawings

Some of the objects and advantages of the present invention having been stated, others will be more fully understood from the detailed description that follows and by reference to the accompanying drawings in which:

Fig. 1 illustrates a communications system according to the present invention;

Fig. 2 illustrates parallel encoding according to an embodiment of a communications system according to the present invention;

Fig. 3 illustrates selective recursive decoding according to an embodiment of a communications system according to the present invention;

Fig. 4 illustrates parallel encoding with error detection according to another embodiment of a communications system according to the present invention;

Fig. 5 illustrates selective recursive decoding according to another embodiment of a communications system according to the present invention;

Fig. 6 illustrates selective recursive decoding according to another embodiment of a communications system according to the present invention;

Fig. 7 illustrates operations for communicating a source sequence over a communications medium according to the present invention;

Fig. 8 illustrates selective recursive coding operations according to an aspect of the present invention;

Fig. 9 illustrates selective recursive decoding operations according to another aspect of the present invention; and

Fig. 10 illustrates combined recursive and nonrecursive decoding operations according to another aspect of the present invention.

Detailed Description of Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

Fig. 1 illustrates a communications system **100** according to the present invention. The communications system **100** includes encoding means **110** for encoding a source sequence of symbols **105** according to respective first and second

error correction codes to produce respective first and second encoded sequences **115a, 115b**. The first and second encoded sequences **115a, 115b** are processed by communications symbol processing means **120** to produce a communication signal **125** which is communicated over a communications medium by communications signal communicating means **130**. The communicated communications signal **135** is processed by communications signal processing means **140** to produce first and second received sequences **145a, 145b** which correspond to the first and second encoded sequences **115a, 115b**. To produce an estimate **155** of a symbol of the source sequence **150**, selective recursive decoding means **150** recursively decode the first and second received sequences **145a, 145b** according to the respective first and second error correction codes augmented by previous estimates of the symbol to repeatedly produce revised estimates of the symbol until an estimate of the symbol satisfying a predetermined reliability criterion, e.g., a symbol having an associated reliability metric within a predetermined range, is obtained.

Those skilled in the art will appreciate that the encoding means **110**, the communication symbol processing means **120**, communications signal communicating means **130**, communications signal processing means **140**, and selective recursive decoding means **150** may be implemented using a variety of hardware, software or combinations thereof. For example, the encoding means **110** may be implemented using software running on a computer, microprocessor or other data processing apparatus, firmware running on special purpose hardware such as digital signal processing (DSP) chips, or combinations thereof. The communications symbols processing means **120** may include such commonly used communications components as multiplexers, interleavers, digital to analog converters (D/As), modulators, and the like. Functions of the encoding means **110** and the communications symbols processing means **120** may, for example, be integrated in special purpose hardware and/or software such as an application specific integrated circuit (ASIC), or may be distributed among different components. Communications signal communicating means **130** may be implemented with commonly used communications components such as amplifiers, antennas, receivers, and the like which are appropriate for the communications medium used, e.g., a radio link, fiber

optic link, coaxial cable and the like. The operations of these components are well-known to those skilled in the art and need not be described in greater detail herein.

According to preferred embodiments, the encoding means **110** and the communications symbol processing means **120** perform a parallel coding function which produces a communication signal **125** which represents a combination of separately encoded versions of the source sequence **105**. Refering to Fig. 2, encoding means **110** is illustrated including first encoding means **112** for encoding the source sequence **105** according to a first error correction code. Second encoding means **116** is also provided for encoding the source sequence **105** according to a second error correction code, preferably after interleaving in interleaving means **114**. The first and second encoded sequences **115a, 115b** thereby produced are multiplexed in multiplexing means **122** and processed in processing means **124** to produce the communications signal **125**. As described above, these elements of the encoding means **110** and the communications symbol processing means **120** may be implemented using special-purpose hardware, software running on special or general purpose data processors, or combinations thereof.

The communicated communications signal **135** is decoded using a selective recursive decoding scheme. According to one embodiment illustrated in Fig. 3, the communicated communications signal **135**, which generally corresponds to the communications signal **125** subject to noise, fading and other disturbances introduced by the communications medium and/or the communications signal communicating means **130**, is processed in communications signal processing means **140**. In particular, the communicated signal **135** preferably is processed in processing means **142**, e.g., a matched filter and associated sampler, to produce a sequence of symbols which is then demultiplexed in demultiplexing means **144**, preferably according to the multiplexing sequence used in the communications symbol processing means **120**, to produce the first and second received sequences **145a, 145b** corresponding to the first and second encoded sequences **115a, 115b**.

For the embodiment of an apparatus **300** for decoding an encoded communications signal illustrated in Fig. 3, the selective recursive decoding means **150** includes first and second soft output decoding means **152a, 152b** for decoding the

respective first and second received sequences **145a, 145b** according to the respective first and second error correction codes. Each of the first and second soft output decoding means **152a, 152b** produces a soft output **153a, 153b** indicating a reliability of a symbol estimate produced by the soft output decoding means **152a, 152b**. The soft output **153a, 153b** from a soft output decoding means **152a, 152b** is fed back into the other decoding means **152a, 152b** for use in augmenting the decoding of the first and second received sequences **145a, 145b**.

Those skilled in the art will appreciate that the first and second soft output decoding means **152a, 152b** may utilize a number of different decoding techniques or algorithms. For example, the first and second soft output decoding means **152a, 152b** may employ a soft output decoder of the type described in United States Patent Application Serial No. 08/699,101 to Hassan et al., commonly assigned to the assignee of the present invention. According to the decoder described therein, a maximum a posteriori (MAP) estimate is generated for a symbol which is to be decoded, and then a soft information value is produced for each bit position in the symbol, the soft information output providing an indication of the relative probabilities of a particular bit having a particular binary value. Other types of decoders which produce a soft information output which may be used with the present invention include, for example, a symbol estimator as described in *"Optimal decoding of linear codes for minimizing symbol error rate,"* by Bahl et al, or a maximum likelihood sequence estimator utilizing a soft output Viterbi algorithm (SOVA) which produces path metrics, functions of which may be used to indicate a reliability for a symbol produced by the estimator. Those skilled in the art will also appreciate that for systems employing interleaving in conjunction with parallel encoding as in, for example, the illustrated embodiment of Fig. 2, the first and second soft output decoding means **152a, 152b** may incorporate appropriate interleaving, deinterleaving, delay and other element needed to provide appropriate ordering of symbol estimates. Those skilled in the art will appreciate, however, that other parallel coding schemes which do not require similar interleaving, deinterleaving, delay and the like may be used with the present invention, for example, the parallel coding schemes described in the United States Patent Application entitled *"Communications Systems and Methods*

Employing Parallel Coding Without Interleaving," to Hassan et al., assigned to the assignee of the present application and filed concurrently herewith.

Additional embodiments according to the present invention are illustrated in Figs. 4 and 5. Error detection coding means **102** encodes the source sequence **105** according to an error detection code, e.g., a cyclic redundancy code (CRC), to produce a error detection encoded sequence **103**. The error detection encoded sequence is then further encoded in encoding means **110** and processed in communications symbol processing means **120** to produce a communications signal **125**, for example, as described with respect to Fig. 2. Referring to Fig. 5, an apparatus **500** for decoding a communicated communications signal **135** includes communications signal processing means **140** which processes the communicated communications signal **135** to produce first and second received sequences **145a, 145b** as described above, which are then decoded in respective first and second decoding means **252a, 252b** of the selective recursive decoding means **150** to produce symbol estimates **253a, 253b**. To produce a reliability metric to guide recursive decoding in the first and second decoding means **252a, 252b**, symbol estimates **253a, 253b** are further decoded by error detection decoding means **254** according to the error detection code employed in the error detection encoding means **102** of Fig. 4 to produce reliability metrics **256** for the symbol estimates **253a, 253b**. A respective one of the first and second decoding means **252a, 252b** decodes the respective first and second received sequences **145a, 145b** according to the first and second error correction codes to produce a symbol estimate **253a, 253b** for a symbol in the source sequence **105**, augmented by a reliability metric **256** produced for a previous estimate produced by the other of the first and second decoding means **252a, 252b**.

Those skilled in the art will understand the first and second decoding means **252a, 252b** may utilize a variety of hard decision or soft decision decoders. It will be appreciated that use of the error detection encoding, e.g., a relatively simple CRC, to generate reliability metrics allows the illustrated embodiment to utilize hard decision decoders which may be less complex than soft decision decoders. However, those skilled in the art will appreciate that soft decision decoders, for example, the soft output decoders described above may also utilized with the illustrated embodiment.

Those skilled in the art will also appreciate that for systems employing interleaving in conjunction with parallel encoding as in, for example, the illustrated embodiment of Fig. 4, the first and second decoding means **252a, 252b** may incorporate appropriate interleaving, deinterleaving, delay and other element needed to provide appropriate ordering of symbol estimates. Those skilled in the art will appreciate, however, that other parallel coding schemes which do not require similar interleaving, deinterleaving, delay and the like may be used with the present invention as described, for example, in the United States Patent Application entitled *"Communications Systems and Methods Employing Parallel Coding Without Interleaving,"* discussed above.

Fig. 6 illustrates yet another embodiment of selective recursive decoding according to the present invention, in which means for determining a respective signal characteristic **165** for a respective one of the first and second received sequences **145a, 145b**, for example, signal strength determining means **160** for determining a respective signal strength for a respective one of the first and second received sequences **145a, 145b**, is provided to allow for more efficient decoding. In particular, the selective recursive decoding means **150** may use the signal characteristic **165** to determine which of the first and second decoding means **152a, 152b** will first generate an estimate of a symbol in the source sequence **105**. For example, by choosing one of the received sequences **145a, 154b** having the greater signal strength associated therewith, an estimate of a symbol produced by the corresponding decoding means may have a higher reliability, thus potentially allowing a reduction in the number of decoding iterations required to produce an estimate having the desired reliability.

Figures 7-10 are flowchart illustrations of methods and apparatus for processing a communications signal to produce an estimated sequence of information symbols which represents an estimate of the source sequence of information symbols communicated by the communications signal. Those skilled in the art will understand that each block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations, may be implemented with various commonly used communications system components. It will also be understood that portions of the

operations described in the flowchart illustrations may be executed as computer program instructions loaded in a computer or other data processing apparatus, thus producing a machine which provides means for implementing the functions specified in the flowchart blocks and combinations thereof. The computer program may cause operational steps to be performed on the computer or data processing apparatus to produce a computer-implemented process such that the instructions which execute on the computer or data processing apparatus provide steps for implementing the functions of the flowchart blocks or combinations thereof. Accordingly, blocks of the flowchart illustrations support combinations of means for performing the specified functions and combinations of steps for performing the specified functions.

Fig. 7 illustrates operations for communicating a source sequence of symbols over a communications medium (Block 700). The source sequence is encoded according to respective first and second error correction codes to produce respective first and second encoded sequences (Block 710). The first and second sequences are processed to produce a communications signal (Block 720) which is then communicated over a communications medium (Block 730). The communicated communications signal, which may be subject to corruption due to noise, fading and other effects, is then processed to produce first and second received sequences corresponding to the first and second encoded sequences (Block 740). The first and second received sequences are then recursively decoded to produce estimates of a symbol of the source sequence until an estimate satisfying a predetermined reliability criterion is obtained (Block 750).

Operations for selectively recursively decoding the first and second received sequences according to one aspect of the present invention are illustrated in Fig. 8 (Block 800). A first one of the received sequences is decoded according to the corresponding error correction code to produce a first estimate of a symbol of the source sequence (Block 810). If the first estimate satisfies a predetermined reliability criterion (Block 820), e.g., has a soft output value within a predetermined range, the first estimate may be output (Block 870). If the first estimate does not satisfy the predetermined reliability criterion, a second one of the received sequences is decoded according to its corresponding error code augmented by the first estimate of the

symbol, to produce a second estimate of the symbol (Block 830). Those skilled in the art will appreciate that if the reliability of the first estimate is questionable, for example, if the first estimate has a reliability within a predetermined range which may cause the first estimate to incorrectly bias the second estimate, the second estimate may alternatively be produced by decoding the second one of the received sequences according to its corresponding error correction code augmented by a predetermined reference value. As with the first estimate, if the second estimate satisfies the predetermined reliability criterion (Block 840), it may be output. Otherwise, the first one of the received sequences is decoded again according to its corresponding error correction code, this time augmented by the second estimate of the symbol, to produce a new estimate of the symbol (Block 850). The reliability of the estimate is tested (Block 860), with new estimates being generated until an estimate satisfying the predetermined reliability criterion is produced.

An example of how an output of one decoder can be used to augment a second decoder will now be explained with reference to Figs. 4 and 5. Assuming systematic encoding, let x denote information bits of a source sequence **105**, y denote parity bits produced by the first encoding means **112** and z denote parity bits produced by the second encoding means **116**. At the decoding apparatus **500**, a demodulator may produce sequences $\hat{x}$, $\hat{y}$, and $\hat{z}$, corresponding to x, y, and z. The first decoding means **252a** processes $\hat{x}$ and $\hat{y}$, augmented by information from the second decoding means **252b**, and the second decoding means **252b** processes $\hat{x}$ and $\hat{z}$, augmented by information from the first decoding means **252a**.

In particular, the first decoding means **252a** accepts sequences $\hat{x}$ and $\hat{y}$, in addition to bias information $L_j^{(2)}$ from the second decoding means **252b**. The first time the first decoding means **252a** operates, $L_j^{(2)}$ may not be available, and thus may be replaced by a value "1" for all j. From $L_j^{(2)}$ the first decoding means **252a** first computes:

$$q_j^{(2)}(0)=\frac{L_j^{(2)}}{(1+L_j^{(2)})}$$

and

$$q_j^{(2)}(1)=1-q_j^{(2)}.$$

The first decoding means **252a** next computes a likelihood ratio $l_i^{(1)}$ for bit x_i:

$$l_i^{(1)}=\frac{\sum_{x:x_i=0}\prod_j p(\hat{x}_j|x_j)\prod_k p(\hat{y}_k|y_k)\prod_l q_l^{(2)}(x_l)}{\sum_{x:x_i=1}\prod_j p(\hat{x}_j|x_j)\prod_k p(\hat{y}_k|y_k)\prod_l q_l^{(2)}(x_l)},$$

where $p(\hat{x}_j|x_j)$ and $p(\hat{y}_k|y_k)$ may depend on a channel model. From the viewpoint of the first decoding means **252a** , a value $l_i^{(1)}>1$ indicates that $x_i=0$ and a value $l_i^{(1)}\leq 1$ indicates that $x_i=1$,. The first decoding means **252a** also computes "intrinsic" information

$$M_i^{(1)}=\frac{p(\hat{x}_i|x_i=0)}{p(\hat{x}_i|x_i=1)},$$

and "extrinsic" information

$$L_i^{(1)}=\frac{l_i^{(1)}}{M_i^{(1)}}.$$

The second decoding means **252b** may operate similarly, accepting sequences $\hat{x}$ and $\hat{z}$, as well as bias information $L_j^{(1)}$ from the first decoding means **252a**. The

second decoding means **252b** may compute $l_i^{(2)}$ and $L_i^{(2)}$ in the same manner that the first decoding means **252a** computes $l_i^{(1)}$ and $L_i^{(1)}$. From the viewpoint of the second decoding means **252b**, a value $l_i^{(2)}>0$ indicates that $x_i=0$, and a value $l_i^{(2)}\leq 0$ indicates that $x_i=1$. The second decoding means **252b** sends extrinsic information $L_i^{(2)}$ as bias information to the first decoding means **252a**. Monotonic functions of the log-likelihood, intrinsic and extrinsic information may also be used instead of the above expressions. An example of monotonic function is the natural logarithm.

In a variation on the operations illustrated in Fig. 9, Fig. 8 illustrates operations (Block **900**) for decoding the first and second received sequences wherein decoding is guided by a determination of a signal characteristic for each of the received sequences, here shown as a signal strength (Block **910**). The received sequence having the greater signal strength is first decoded according to its corresponding error correction code to produce a first estimate of a symbol in the source sequence (Block **920**). If the first estimate satisfies a predetermined reliability criterion (Block **930**), the estimate may be output (Block **980**). If not, a second one of the received sequences is decoded according to its corresponding error correction code augmented by the first estimate or, alternatively, a predetermined reference value, to produce a new estimate of the symbol (Block **940**). As with the first estimate, if the new estimate satisfies the predetermined reliability criterion (Block **950**), it may be output (Block **980**). If not, this estimate is used to generate a new estimate of the symbol from the first one of the received sequences (Block **960**), the reliability of which is in turn tested (Block **970**) to determine if further decoding is necessary.

Those skilled in the art will appreciate that the operations of Figs. 8 and 9 may include other steps, for example, interleaving or deinterleaving appropriate to compensate for interleaving in the original encoding of the communications signal. Those skilled in the art will also appreciate that additional processing such as additional interleaving, encoding or decoding may also be practiced with the present

invention.

Fig. 10 illustrates a aspect of the present invention whereby only selected symbols of the source sequence are iteratively estimated. According to this embodiment, operations for decoding the first and second received sequences (Block 1000) include nonrecursively decoding at least one of the first and second sequences to produce estimates of a first group of symbols in the source sequence (Block 1010). For example, one of the first and second sequences could be decoded, for example, by using a signal strength criterion as described in reference to Fig. 6 and 9, to produce an estimate for a symbol from the first group. The symbols from the first group might include, for example, less significant bits of voice or other data. As accuracy may not be particularly important for these bits, they may be nonrecursively decoded in order to reduce computational overhead. The first and second received sequences may be selectively recursively decoded (Block 1020), as described above, to produce more accurate estimates of a second group of symbols of the source sequence, for example, more significant bits of a data stream.

In the drawings and specification, there have been disclosed typical embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

THAT WHICH IS CLAIMED IS:

1. A communications system, comprising:

encoding means for encoding a source sequence according to respective first and second error correction codes to produce respective first and second encoded sequences of symbols;

communications symbol processing means, responsive to said encoding means, for processing the first and second encoded sequences to produce a communications signal;

communications signal communicating means, responsive to said communications symbol processing means, for communicating the communications signal over a communications medium;

communications signal processing means, responsive to said communications signal communicating means, for processing the communicated communications signal to produce first and second received sequences of symbols corresponding to the first and second encoded sequences, respectively; and

selective recursive decoding means, responsive to said communications signal processing means, for selectively recursively decoding the first and second received sequences according to said respective first and second codes augmented by previous estimates of a symbol of the source sequence to repeatedly produce revised estimates of the symbol until a revised estimate satisfying a predetermined reliability criterion is obtained.

2. A system according to Claim 1:

wherein said encoding means comprises:

first encoding means for encoding the source sequence according to said first error correction code to produce the first encoded sequence; and

second encoding means for encoding the source sequence according to said second error correction code to produce the second encoded sequence; and

wherein said communications symbols processing means comprises:

multiplexing means, responsive to said first and second encoding means, for multiplexing the first and second encoded sequences to produce a multiplexed sequence of symbols; and

means, responsive to said multiplexing means, for processing the multiplexed sequence to produce the communications signal.

3. A system according to Claim 2, wherein said encoding means further comprises interleaving means for interleaving the source sequence to produce an interleaved source sequence, and wherein one of said first and second encoding means is responsive to said encoding means for encoding the interleaved source sequence.

4. A system according to Claim 1, wherein said selective recursive decoding means comprises:

means for maximum likelihood decoding the first received sequence to produce a first estimate of a symbol of the source sequence and a path metric associated therewith; and

means, responsive to said means for maximum likelihood decoding, for decoding the second received sequence to produce a second estimate of the symbol if a predetermined function of the path metric associated with the first estimate is outside of a predetermined range.

5. A system according to Claim 1, wherein said selective recursive decoding means comprises:

means for maximum a posteriori (MAP) decoding the first received sequence to produce a first MAP estimate of a symbol of the source sequence and a reliability metric associated therewith; and

means, responsive to said means for MAP decoding, for decoding the second received sequence to produce a second estimate of the symbol if the reliability metric associated with the first MAP estimate is outside of a predetermined range.

6. A system according to Claim 1, further comprising means for

nonrecursively decoding at least one of the first and second received sequences according to the associated error correction codes to produce estimates of a first group of symbols in the source sequence, and wherein said selective recursive decoding means comprises means for recursively decoding the first and second received sequences to produce estimates of a second group of symbols of the source sequence.

7. A system according to Claim 6, wherein said second group of symbols represents information of a greater importance than information represented by said first group of symbols.

8. A system according to Claim 7, wherein said source sequence includes symbols ranging from a least significant symbol to a most significant symbol, and wherein said second group of symbols includes symbols of greater significance than symbols included in the first group of symbols.

9. A system according to Claim 1, further comprising error detection encoding means for encoding the source sequence according to an error detection code to produce an error detection encoded sequence, and:

wherein said encoding means comprises means for encoding the error detection encoded sequence according to said first and second error correction codes to produce the first and second encoded sequences;

wherein said selective recursive decoding means comprises:

means for decoding the first received sequence according to said first error correction code to produce an estimate of a symbol of the source sequence; and

means for decoding the estimate according to the error detection code to produce a reliability metric for the estimate.

10. A system according to Claim 9 wherein the error detection code comprises a cyclic redundancy code (CRC).

11. A system according to Claim 1 wherein said selective recursive decoding means comprises means for first decoding one of the received sequences having a preferred signal characteristic associated therewith.

12. A system according to Claim 11, further comprising means for determining a respective signal characteristic for a respective one of the received sequences.

13. A system according to Claim 11, wherein said means for first decoding one of the received sequences having a preferred signal characteristic associated therewith comprises means for first decoding a first one of the received sequences having a greater signal strength.

14. A system according to Claim 13, further comprising means for determining a respective signal strength for a respective one of the received sequences.

15. A system according to Claim 1, wherein said selective recursive decoding means comprises:

means for decoding the first received sequence to produce a first estimate of a symbol of the source sequence, the first estimate having a reliability associated therewith; and

means for decoding the second received sequence according to the second error correction code augmented by the first estimate of the symbol of the source sequence to produce a second estimate of the symbol if the first estimate of the symbol satisfies a first reliability criterion, and for decoding the second received sequence according to the second error correction code augmented by a predetermined reference value if the first estimate of the symbol satisfies a second reliability criterion.

16. A system according to Claim 15, wherein said first predetermined

reliability criterion represents a greater reliability than said second predetermined reliability criterion.

17. A system according to Claim 1, wherein said selective recursive decoding means comprises soft output decoding means for decoding at least one of the first and second received sequences to produce a soft output indicating a reliability of an estimate of a symbol of the source sequence.

18. A system according to Claim 17, wherein said selective recursive decoding means comprises:

first soft output decoding means, responsive to said communications signal processing means, for decoding the first received sequence according to the first error correction code; and

second soft output decoding means, responsive to said communications signal processing means, for decoding the second received sequence according to the second error correction code;

wherein said first soft output decoding means is responsive to said second soft output decoding means to decode the first received sequence according to said first error correction code augmented by a soft output produced by said second soft output decoding means to produce a first estimate of a symbol of the source sequence if a previous estimate of the symbol produced by said second soft output decoding means fails to satisfy a predetermined reliability criterion, and

wherein said second soft output decoding means is responsive to said first soft output decoding means to decode the second received sequence according to said second error correction code augmented by a soft output produced by said first soft output decoding means to produce a second estimate of a symbol of the source sequence if a previous estimate of the symbol produced by said second soft output decoding means fails to satisfy a predetermined reliability criterion.

19. A system according to Claim 1, further comprising error detection encoding means for encoding the source sequence according to a error detection code

to produce an error detection encoded sequence, and:

wherein said encoding means comprises means for encoding the error detection encoded sequence according to the first and second error correction codes to produce the first and second encoded sequences; and

wherein said selective recursive decoding means comprises:

first decoding means, responsive to said communications signal processing means, for decoding the first received sequence according to said first error correction code to produce an estimate of a symbol of the source sequence; and

second decoding means, responsive to said communications signal processing means, for decoding the second received sequence according to the second error correction code to produce an estimate of a symbol of the source sequence; and

error detection decoding means, responsive to said first and second decoding means, for decoding an estimate produced by said first decoding means or by said second decoding means to thereby produce a reliability metric for the estimate,

wherein said first decoding means is responsive to said error detection decoding means to decode the first received sequence according to said first error correction code augmented by a reliability metric produced by said error detection decoding means to produce a first estimate of a symbol of the source sequence if the reliability metric produced by said error detection decoding means indicates that a previous estimate of the symbol produced by said second decoding means fails to satisfy a predetermined reliability criterion, and

wherein said second decoding means is responsive to said error detection decoding means to decode the second received sequence according to said second error correction code augmented by a reliability metric produced by said error detection decoding means to produce a second estimate of a symbol of the source sequence if the reliability metric produced by said error detection decoding means indicates that a previous estimate of the symbol produced by said first decoding means fails to satisfy a predetermined reliability criterion.

20. An apparatus for decoding a communications signal which represents a source sequence encoded to respective first and second error correction codes which

produce respective first and second encoded sequences which are multiplexed to produce the communications signal, the apparatus comprising:

communications signal processing means for processing the communicated communications signal to produce first and second received sequences of symbols corresponding to the first and second encoded sequences, respectively; and

selective recursive decoding means, responsive to said communications signal processing means, for selectively recursively decoding the first and second received sequences according to the respective first and second codes augmented by previous estimates of a symbol of the source sequence to repeatedly produce revised estimates of the symbol until a revised estimate satisfying a predetermined reliability criteria is obtained.

21. An apparatus according to Claim 20, wherein said selective recursive decoding means comprises:

means for maximum likelihood decoding the first received sequence to produce a first estimate of a symbol of the source sequence and a path metric associated therewith; and

means, responsive to said means for maximum likelihood decoding, for decoding the second received sequence to produce a second estimate of the symbol if a predetermined function of the path metric associated with the first estimate is outside of a predetermined range.

22. An apparatus according to Claim 20, wherein said selective recursive decoding means comprises:

means for maximum a posteriori (MAP) decoding the first received sequence to produce a first MAP estimate of a symbol of the source sequence and a reliability metric associated therewith; and

means, responsive to said means for MAP decoding, for decoding the second received sequence to produce a second estimate of the symbol if the reliability metric associated with the first MAP estimate is outside of a predetermined range.

23. An apparatus according to Claim 20, further comprising means for nonrecursively decoding at least one of the first and second received sequences according to the associated error correction codes to produce estimates of a first group of symbols in the source sequence, and wherein said selective recursive decoding means comprises means for recursively decoding the first and second received sequences to produce estimates of a second group of symbols of the source sequence.

24. An apparatus according to Claim 23, wherein said second group of symbols represents information of a greater importance than information represented by the first group of symbols.

25. An apparatus according to Claim 24, wherein said source sequence includes symbols ranging from a least significant symbol to a most significant symbol, and wherein said second group of symbols includes symbols of greater significance than symbols included in the first group of symbols.

26. An apparatus according to Claim 20:

wherein said selective recursive decoding means comprises:

means for decoding the first received sequence according to the first error correction code to produce an estimate of a symbol of the source sequence; and

means for decoding the estimate according to an error detection code to produce the reliability metric for the estimate.

27. An apparatus according to Claim 26, wherein the error detection code comprises a cyclic redundancy code (CRC).

28. An apparatus according to Claim 20, wherein said selective recursive decoding means comprises means for first decoding one of the received sequences having a preferred signal characteristic associated therewith.

29. An apparatus according to Claim 28, further comprising means for determining a respective signal characteristic for a respective one of the received sequences.

30. An apparatus according to Claim 28, wherein said means for first decoding one of the received sequences having a preferred signal characteristic associated therewith comprises means for first decoding one of the received sequences having a greater signal strength.

31. An apparatus according to Claim 30, further comprising means for determining a respective signal strength for a respective one of the received sequences.

32. An apparatus according to Claim 20, wherein said selective recursive decoding means comprises:

means for decoding the first received sequence to produce a first estimate of a symbol of the source sequence, the estimate having a reliability associated therewith; and

means for decoding the second received sequence according to the second error correction code augmented by the estimate of the symbol of the source sequence to produce a second estimate of the symbol if the first estimate satisfies a first predetermined reliability criterion, and for decoding the second received sequence according to the second error correction code augmented by a predetermined reference value to produce the second estimate if the first estimate of the symbol satisfies a second predetermined reliability criterion.

33. An apparatus according to Claim 32, wherein said first predetermined reliability criterion represents a greater reliability than said second predetermined reliability criterion.

34. An apparatus according to Claim 20, wherein said selective recursive

decoding means comprises soft output decoding means for decoding at least one of the first and second received sequences to produce a soft output indicating a reliability of an estimate of a symbol of the source sequence.

35. An apparatus according to Claim 34, wherein said selective recursive decoding means comprises:

first soft output decoding means, responsive to said communications signal processing means, for decoding the first received sequence according to the first error correction code; and

second soft output decoding means, responsive to said communications signal processing means, for decoding the second received sequence according to the second error correction code;

wherein said first soft output decoding means is responsive to said second soft output decoding means to decode the first received sequence according to said first error correction code augmented by a soft output produced by said second soft output decoding means to produce a first estimate of a symbol of the source sequence if a previous estimate of the symbol produced by said second soft output decoding means fails to satisfy a predetermined reliability criterion, and

wherein said second soft output decoding means is responsive to said first soft output decoding means to decode the second received sequence according to said second error correction code augmented by a soft output produced by said first soft output decoding means to produce a second estimate of a symbol of the source sequence if a previous estimate of the symbol produced by said second soft output decoding means fails to satisfy a predetermined reliability criterion.

36. An apparatus according to Claim 20, wherein said selective recursive decoding means comprises:

first decoding means, responsive to said communications signal processing means, for decoding the first received sequence according to said first error correction code to produce an estimate of a symbol of the source sequence; and

second decoding means, responsive to said communications signal processing

means, for decoding the second received sequence according to the second error correction code to produce an estimate of a symbol of the source sequence; and

error detection decoding means, responsive to said first and second decoding means, for decoding an estimate produced by said first decoding means or by said second decoding means to thereby produce a reliability metric for the estimate,

wherein said first decoding means is responsive to said error detection decoding means to decode the first received sequence according to said first error correction code augmented by a reliability metric produced by said error detection decoding means to produce a first estimate of a symbol of the source sequence if the reliability metric produced by said error detection decoding means indicates that a previous estimate of the symbol produced by said second decoding means fails to satisfy a predetermined reliability criterion, and

wherein said second decoding means is responsive to said error detection decoding means to decode the second received sequence according to said second error correction code augmented by a reliability metric produced by said error detection decoding means to produce a second estimate of a symbol of the source sequence if the reliability metric produced by said error detection decoding means indicates that a previous estimate of the symbol produced by said first decoding means fails to satisfy a predetermined reliability criterion.

37. A method of communicating a source sequence of symbols over a communications medium, the method comprising the steps of:

encoding the source sequence according to respective first and second error correction codes to produce respective first and second encoded sequences of symbols;

processing the first and second encoded sequences to produce a communications signal;

communicating the communications signal over the communications medium;

processing the communicated communications signal to produce first and second received sequences of symbols corresponding to the first and second encoded sequences, respectively;

selectively recursively decoding the first and second received sequences according to the associated error correction codes augmented by previous estimates of a symbol of the source sequence to repeatedly produce revised estimates of the symbol until an estimate satisfying a predetermined reliability criteria is obtained.

38. A method according to Claim 37:

wherein said step of encoding comprises the steps of:

encoding the source sequence according to the first error correction code to produce the first encoded sequence; and

encoding the source sequence according to the second error correction code to produce the second encoded sequence; and

wherein said step of processing the first and second encoded sequences comprises the steps of:

multiplexing the first and second encoded sequences to produce a multiplexed sequence of symbols; and

processing the multiplexed sequence to produce the communications signal.

39. A method according to Claim 38, wherein said step of encoding the source sequence according to the second error correction code is preceded by the step of interleaving the source sequence to produce an interleaved source sequence, and wherein said step of encoding the source sequence according to the second error correction code comprises the step of encoding the interleaved source sequence to produce the second encoded sequence.

40. A method according to Claim 37, wherein said step of selectively recursively decoding comprises the steps of:

maximum likelihood decoding the first received sequence to produce a first estimate of a symbol of the source sequence and a path metric associated therewith; and

decoding the second received sequence to produce a second estimate of the

first symbol if a predetermined function of the path metric associated with the first estimate is outside of a predetermined range.

41. A method according to Claim 37, wherein said step of selectively recursively decoding comprises the steps of:

maximum a posteriori (MAP) decoding the first received sequence to produce a first MAP estimate of a symbol of the source sequence and a reliability metric associated therewith; and

decoding the second received sequence to produce a second estimate of the first symbol if the reliability metric associated with the first MAP estimate is outside of a predetermined range.

42. A method according to Claim 37, further comprising the step of nonrecursively decoding at least one of the first and second received sequences according to the associated error correction code to produce estimates of a first group of symbols in the source sequence, and wherein said step of selectively recursively decoding comprises the step of recursively decoding the first and second received sequences to produce estimates of a second group of symbols of the source sequence.

43. A method according to Claim 42, wherein said second group of symbols represents information of a greater importance than information represented by the first group of symbols.

44. A method according to Claim 43, wherein said source sequence includes symbols ranging from a least significant symbol to a most significant symbol, and wherein said second group of symbols includes symbols of greater significance than symbols included in the first group of symbols.

45. A method according to Claim 37:

wherein said step of encoding is preceded by the step of encoding the source sequence according to a error detection code; and

wherein said step of selectively recursively decoding comprises the steps of:

decoding the first received sequence according to the first error correction code to produce an estimate of a symbol of the source sequence; and

decoding the estimate according to the error detection code to produce the reliability metric for the estimate.

46. A method according to Claim 45 wherein the error detection code comprises a cyclic redundancy code (CRC).

47. A method according to Claim 37, wherein said step of selectively recursively decoding comprises the steps of:

decoding the first received sequence to produce a first estimate of a symbol of the source sequence; and

decoding the second received sequences according to the second error correction code augmented by the first estimate of the symbol if the first estimate satisfies a first reliability criterion, and decoding the second received sequence according to the second error correction code augmented by a predetermined reference value if the first estimate satisfies a second reliability criterion.

48. A method according to Claim 47, wherein the first predetermined reliability criterion represents a greater reliability than the second predetermined reliability criterion.

49. A method of communicating a source sequence of symbols over a communications medium, the method comprising the steps of:

encoding the source sequence according to respective first and second error correction codes to produce respective first and second encoded sequences of symbols;

processing the first and second encoded sequences to produce a communications signal;

communicating the communications signal over the communications medium;

processing the communicated communications signal to produce first and second received sequences of symbols corresponding to the first and second encoded sequences, respectively;

decoding the first received sequence according to the first error correction code to produce a first estimate of a first symbol of the source sequence, the first estimate having a reliability associated therewith; and then

decoding the second received sequence according to the second error correction code augmented by the first estimate of the first symbol to produce a revised estimate of the first symbol if the first estimate of the first symbol fails to satisfy a predetermined reliability criterion.

50. A method according to Claim 49, wherein said step of decoding the first received sequence is followed by the step of decoding one of the received sequences according to the associated error correction code to produce a first estimate of a second symbol of the source sequence if the first estimate of the first symbol satisfies a predetermined reliability criterion.

51. A method according to Claim 49 wherein the first and second received sequences have signal characteristics associated therewith, and wherein the first received sequence has a preferred signal characteristic.

52. A method according to Claim 51, wherein said step of decoding the first received sequence is preceded by the step of determining a respective signal characteristic for a respective one of the first and second received sequences.

53. A method according to Claim 51, wherein said first received sequence has a greater signal strength than the second received sequence.

54. A method according to Claim 52, wherein said step of decoding the first received sequence is preceded by the step of determining a respective signal

strength for a respective one of the first and second received sequences.

FIG. 1

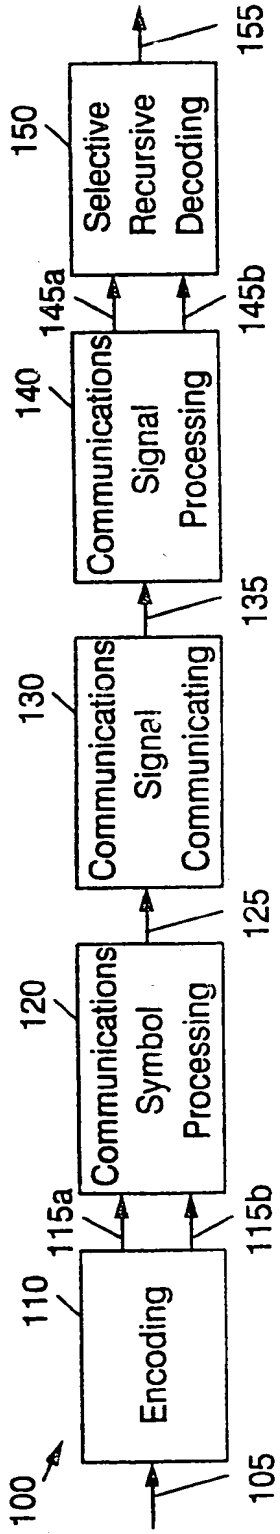
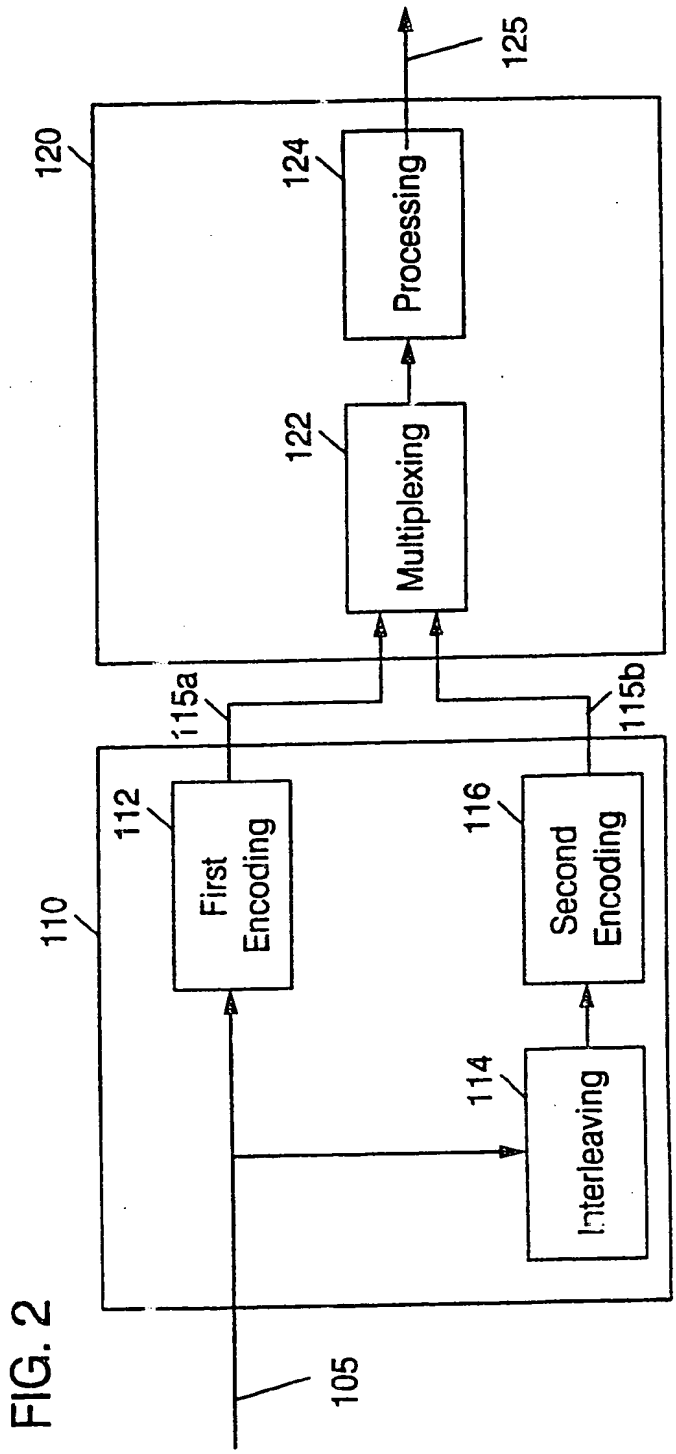

100
105
110
Encoding
115a
115b
120
Communications Symbol Processing
125
130
Communications Signal Communicating
135
140
Communications Signal Processing
145a
145b
150
Selective Recursive Decoding
155

FIG. 2


105
110
112
First Encoding
114
Interleaving
115a
115b
116
Second Encoding
120
122
Multiplexing
124
Processing
125

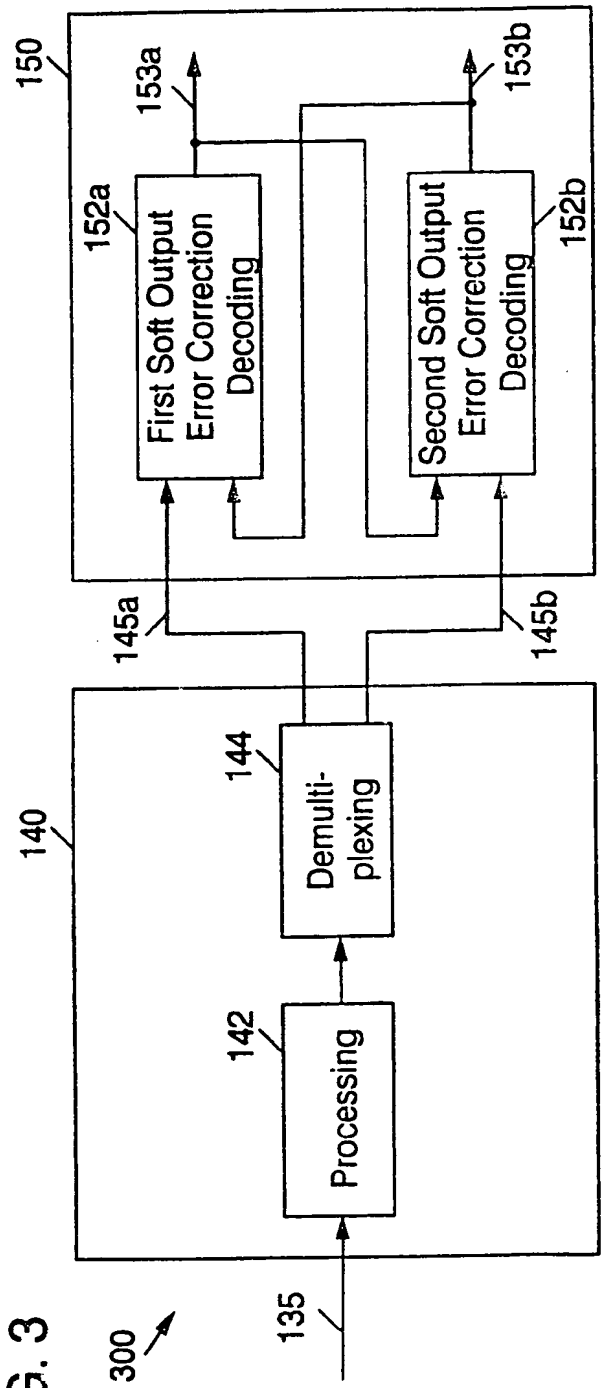

150
153a
153b
152a
First Soft Output Error Correction Decoding
Second Soft Output Error Correction Decoding
152b
145a
145b
140
144
Demulti-plexing
142
Processing
135
300

FIG. 3

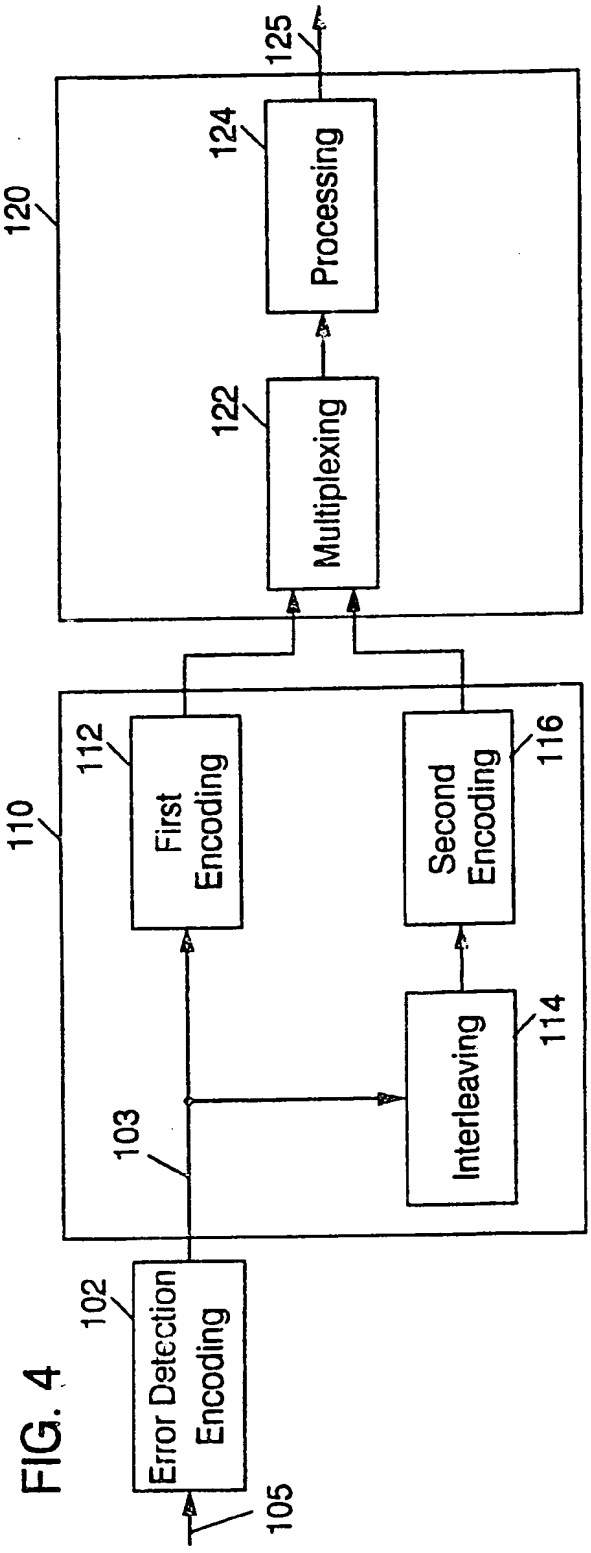

125
124
Processing
120
122
Multiplexing
110
112
First Encoding
Second Encoding
116
103
Interleaving
114
102
Error Detection Encoding
105

FIG. 4

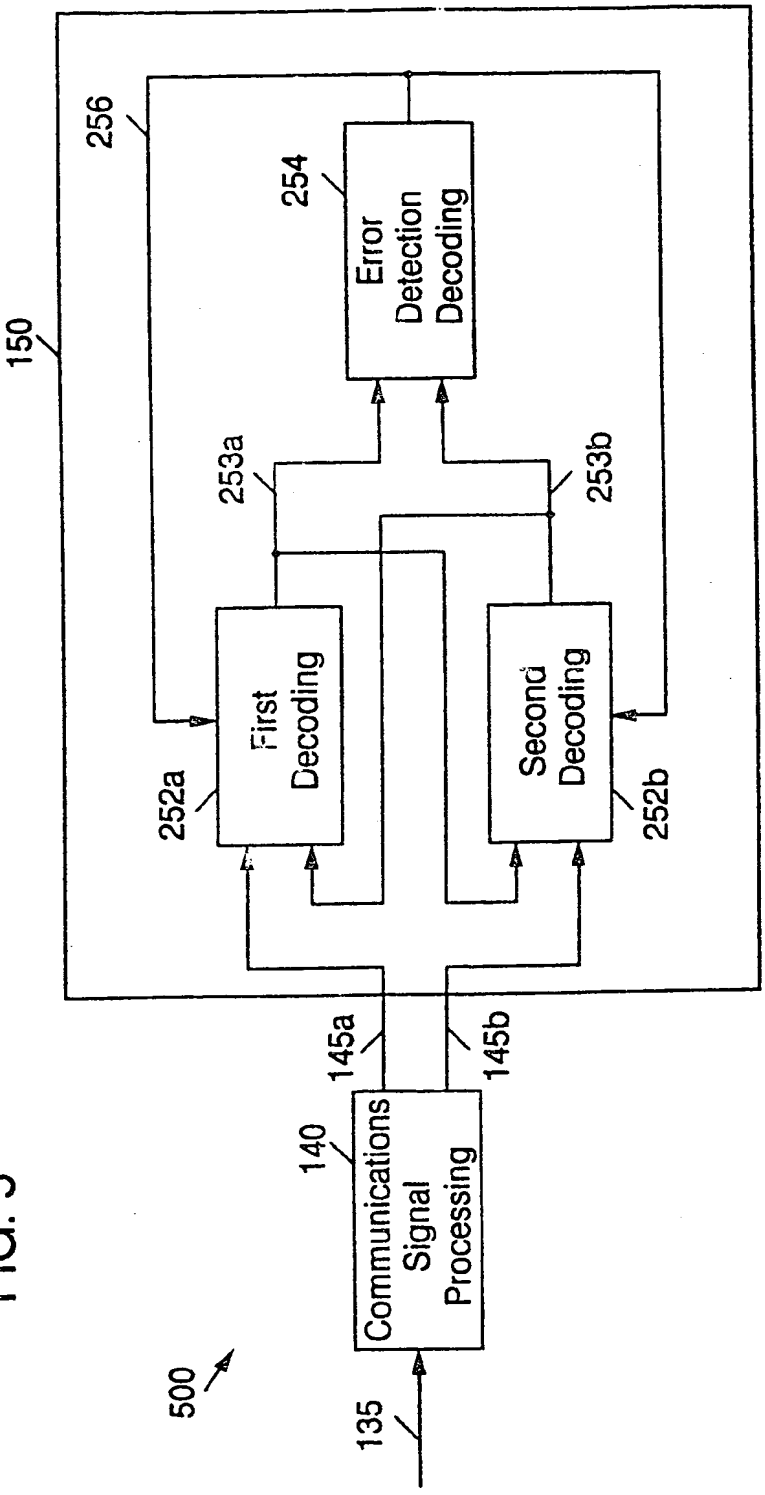

256
254
Error Detection Decoding
150
253a
253b
First Decoding
Second Decoding
252a
252b
145a
145b
140
Communications Signal Processing
500
135

FIG. 5

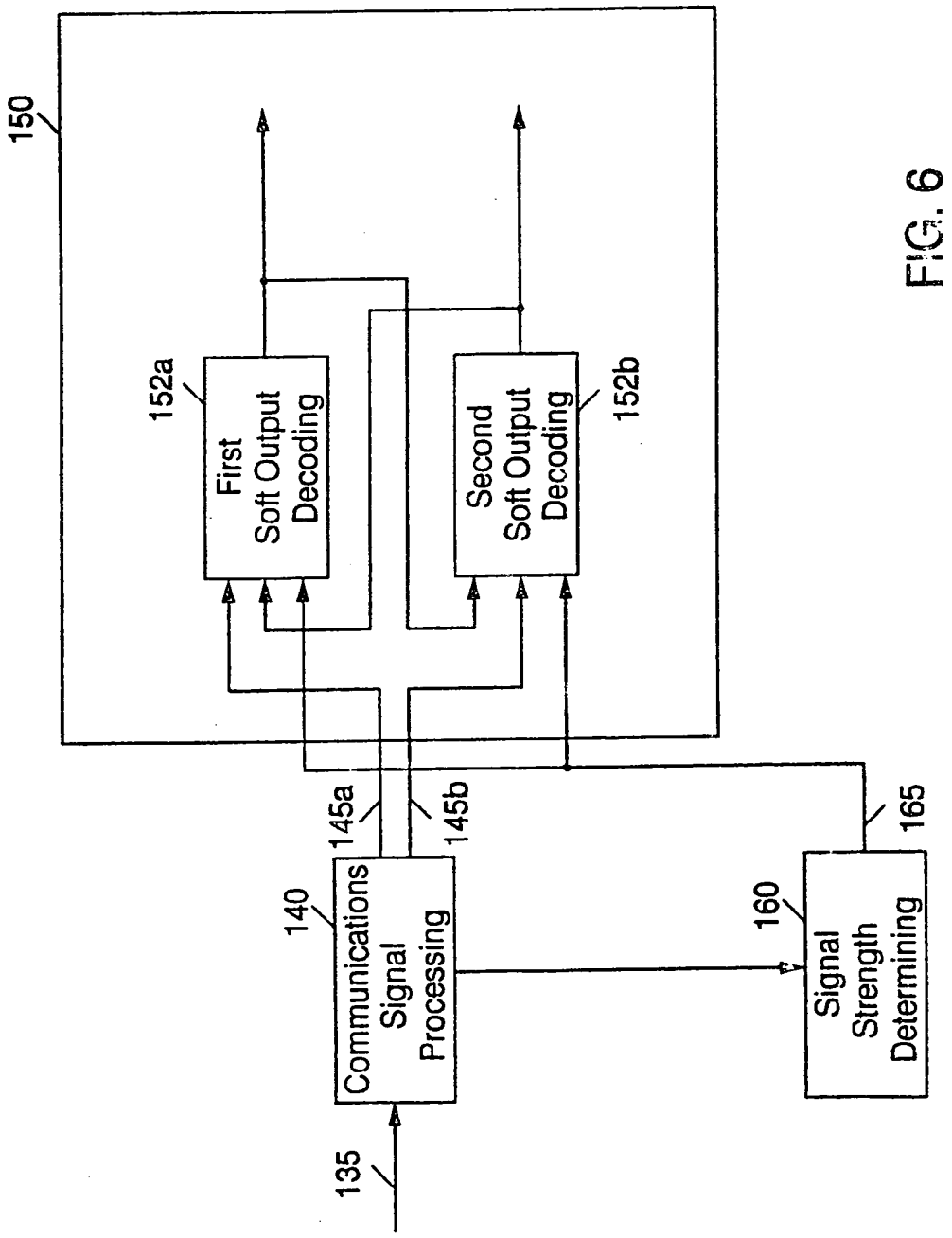
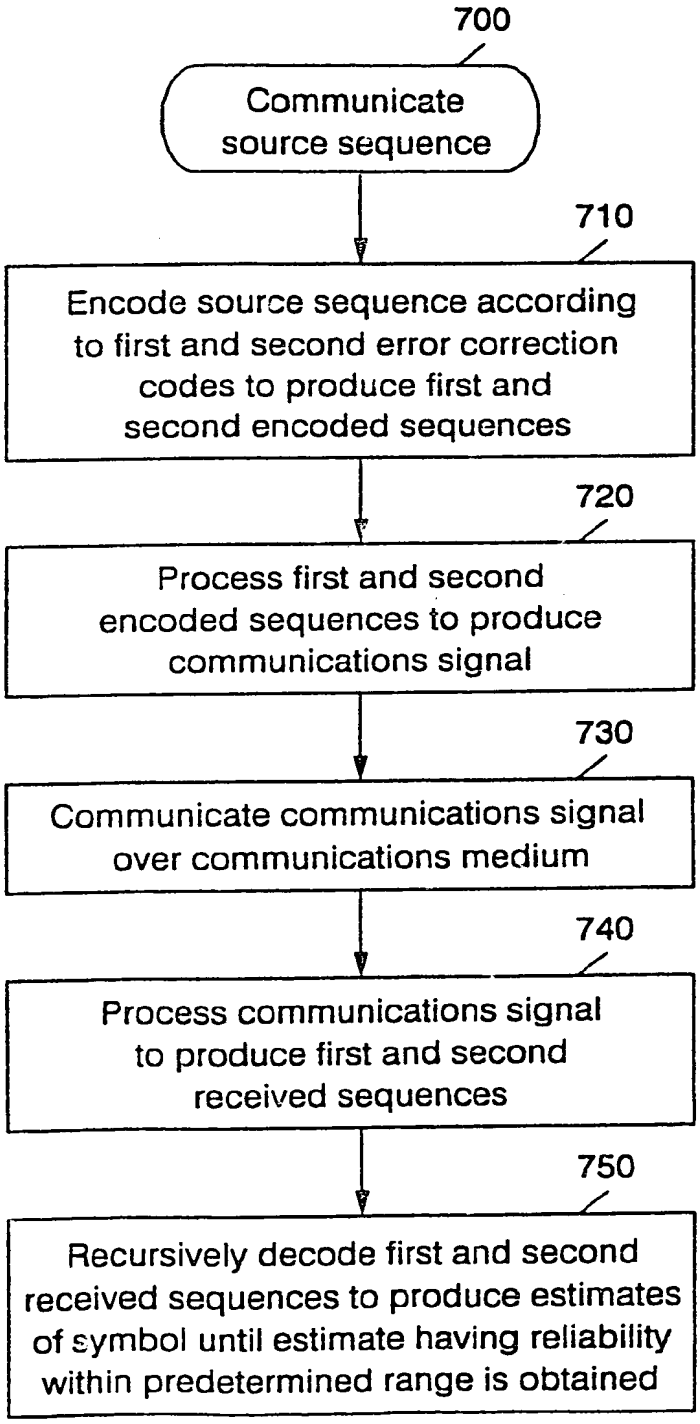

150
152a
First Soft Output Decoding
Second Soft Output Decoding
152b
145a
145b
165
140
Communications Signal Processing
160
Signal Strength Determining
135

FIG. 6

FIG. 7


700
Communicate source sequence
710
Encode source sequence according to first and second error correction codes to produce first and second encoded sequences
720
Process first and second encoded sequences to produce communications signal
730
Communicate communications signal over communications medium
740
Process communications signal to produce first and second received sequences
750
Recursively decode first and second received sequences to produce estimates of symbol until estimate having reliability within predetermined range is obtained

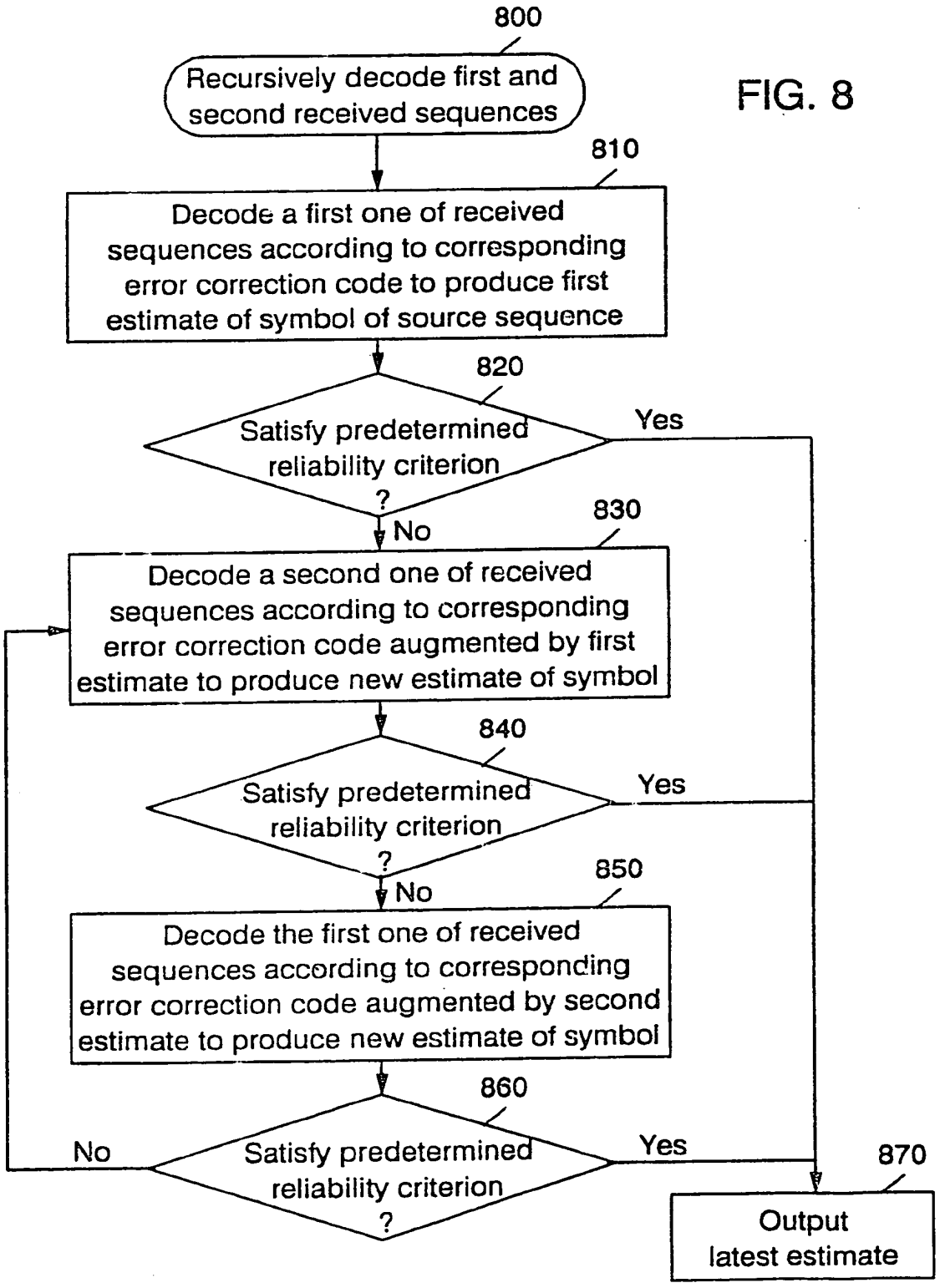

800
Recursively decode first and second received sequences
810
Decode a first one of received sequences according to corresponding error correction code to produce first estimate of symbol of source sequence
820
Satisfy predetermined reliability criterion ?
Yes
No
830
Decode a second one of received sequences according to corresponding error correction code augmented by first estimate to produce new estimate of symbol
840
Satisfy predetermined reliability criterion ?
Yes
No
850
Decode the first one of received sequences according to corresponding error correction code augmented by second estimate to produce new estimate of symbol
860
Satisfy predetermined reliability criterion ?
No
Yes
870
Output latest estimate

FIG. 8

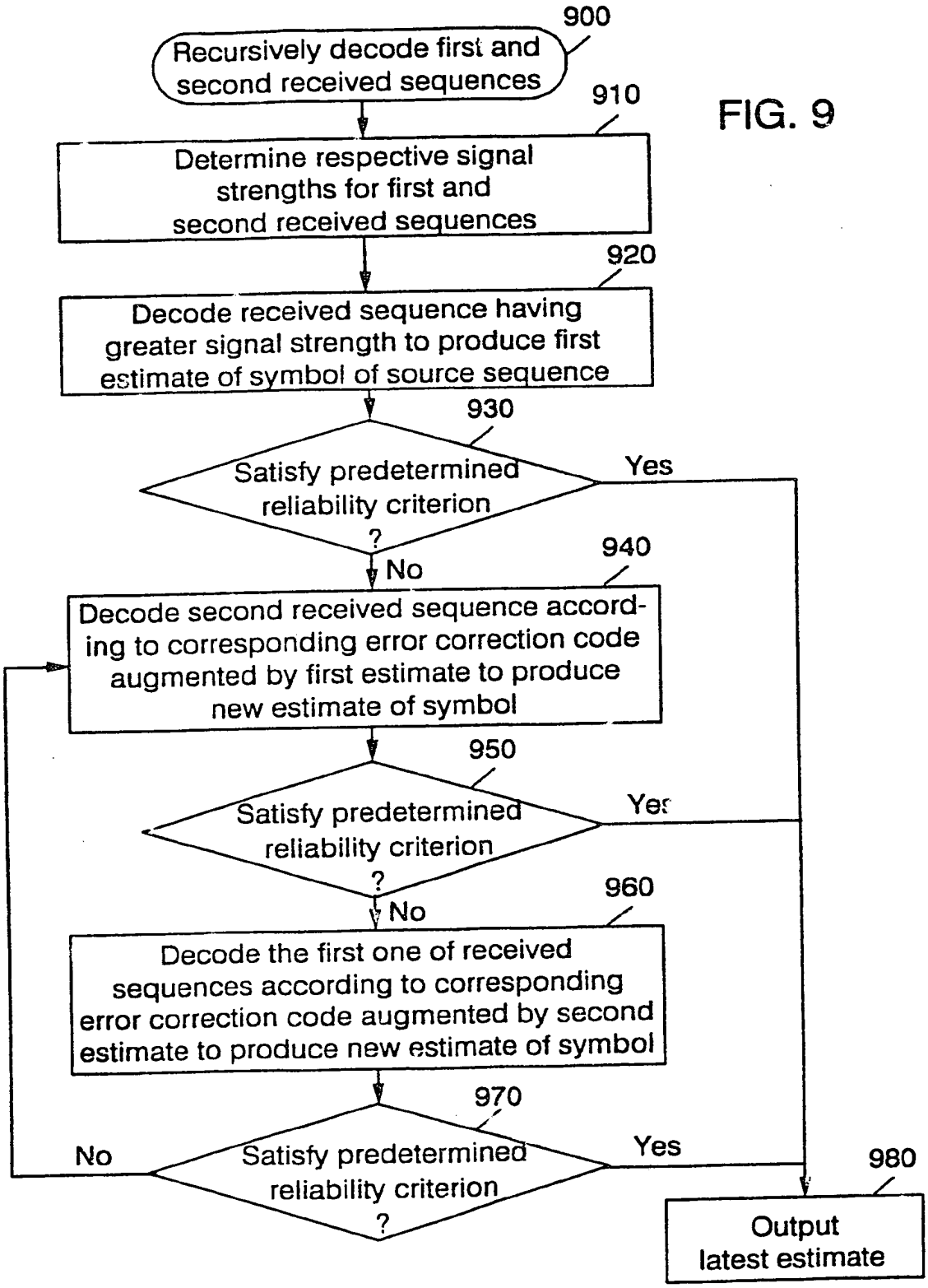
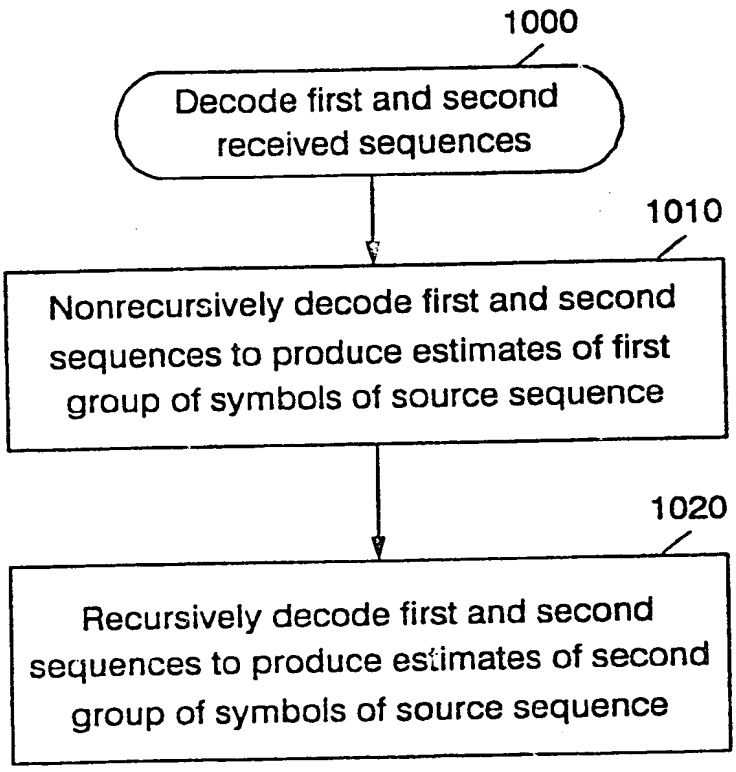

900
Recursively decode first and second received sequences
910
Determine respective signal strengths for first and second received sequences
920
Decode received sequence having greater signal strength to produce first estimate of symbol of source sequence
930
Satisfy predetermined reliability criterion ?
Yes
No
940
Decode second received sequence according to corresponding error correction code augmented by first estimate to produce new estimate of symbol
950
Satisfy predetermined reliability criterion ?
Yes
No
960
Decode the first one of received sequences according to corresponding error correction code augmented by second estimate to produce new estimate of symbol
970
Satisfy predetermined reliability criterion ?
No
Yes
980
Output latest estimate

FIG. 9

FIG. 10


1000
Decode first and second received sequences
1010
Nonrecursively decode first and second sequences to produce estimates of first group of symbols of source sequence
1020
Recursively decode first and second sequences to produce estimates of second group of symbols of source sequence

INTERNATIONAL SEARCH REPORT

Inter onal Application No
PCT/US 98/16731

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L1/00 H03M13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 755 122 A (SIEMENS AG) 22 January 1997 see abstract see page 2, line 15 - line 21 see page 2, line 37 - line 51 see page 3, line 49 - line 56 see figures 1,2 ---	1-3,17, 20,34, 35, 37-39,49
A	US 5 446 747 A (BERROU CLAUDE) 29 August 1995 cited in the application see abstract see column 3, line 15 - line 25 see column 4, line 49 - column 5, line 8 see column 6, line 36 - line 52 see figures 1,2,4 --- -/--	1-4,17, 20, 37-39,49

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 January 1999	01/02/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Inter. ɔnal Application No
PCT/US 98/16731

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 749 211 A (SIEMENS AG) 18 December 1996 see column 1, line 19 - line 23 see column 1, line 46 - line 48 see column 3, line 9 - line 15 see column 3, line 48 - line 53 see column 4, line 37 - column 5, line 22 see figures 1,2	1-3,5, 17,20, 37-39,49

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INTERNATIONAL SEARCH REPORT

information on patent family members

Inter. nal Application No
PCT/US 98/16731

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		US 5761248 A	02-06-1998
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		DE 69215743 T	10-07-1997
		EP 0511141 A	28-10-1992
		EP 0735696 A	02-10-1996
EP 0749211 A	18-12-1996	US 5729560 A	17-03-1998